



Beam dynamics studies of H- beam chopping in a LEBT for PXIE

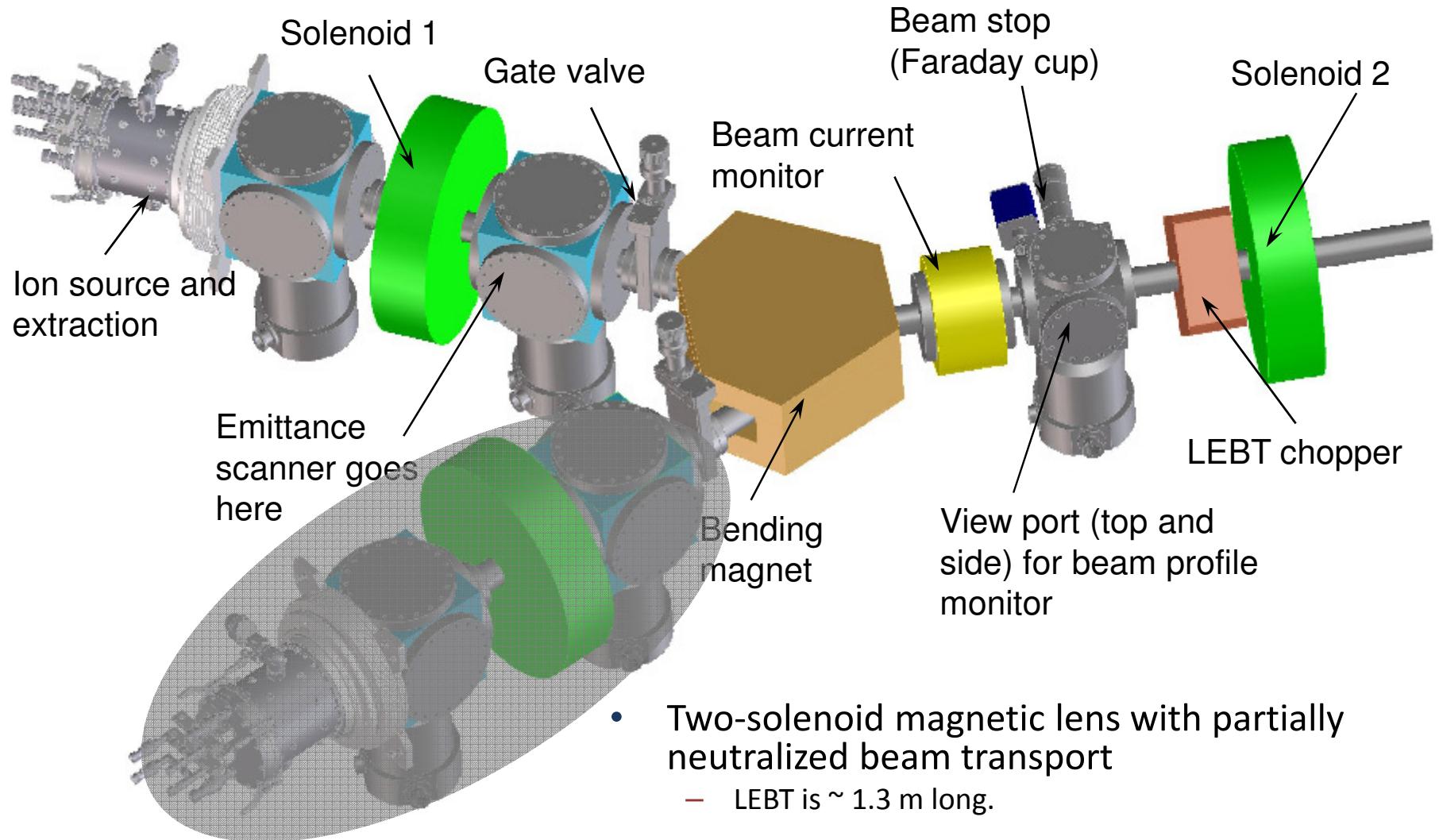
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PXIE LEBT Conceptual Design



PXIE LEBT Optics

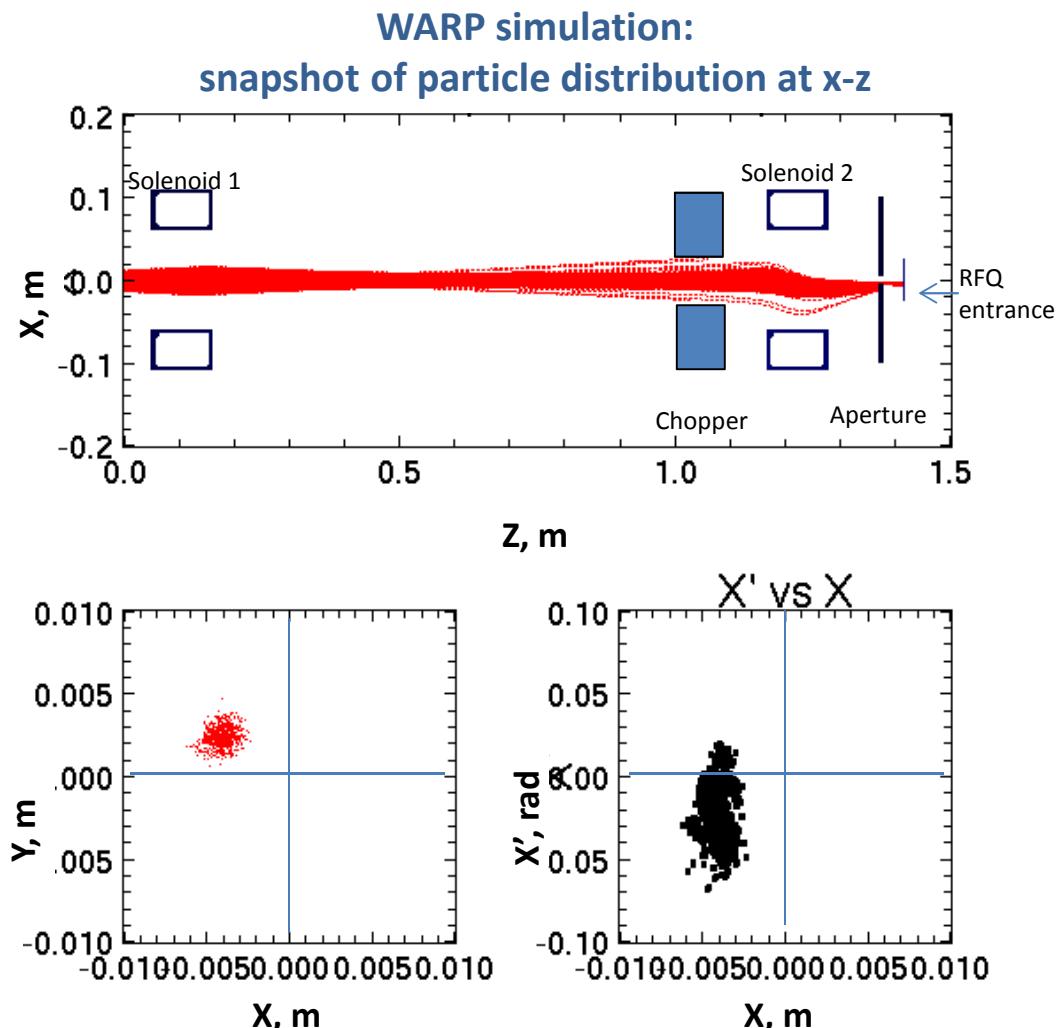
- LEBT beam dynamics has been simulated using various codes
 - Trace 3D
 - Astra
 - TLAT
 - WARP 3D
- All results have good agreement.

$I = 10\text{mA}$

$E_k = 30\text{keV}$

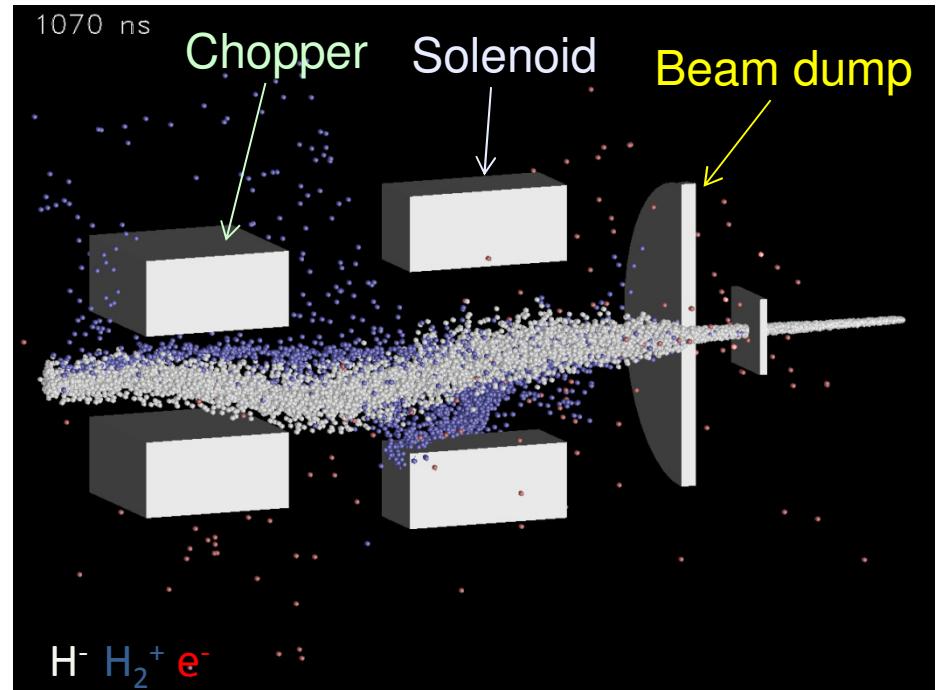
Deflecting voltage: $\pm 650 \text{ V}$

with 90% space charge neutralization throughout the LEBT



LEBT and Chopper Beam Dynamics Simulation

- Partial space charge neutralization will be lost along the beam in the chopper and maybe through the second solenoid.
 - Typical space charge neutralization time $\sim 50 \mu\text{sec}$ at 10^{-6} Torr.
- Beam dynamics study is crucial to investigate the time-dependence of the space charge neutralization in the segment after the chopper
 - Beam stability
 - Emittance growth
- Time-dependent simulation of LEBT chopper using WARP 3D
 - Chopper + solenoids
 - Simulations performed with particle interactions



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Simulation Including Particle Interactions with Background Gas

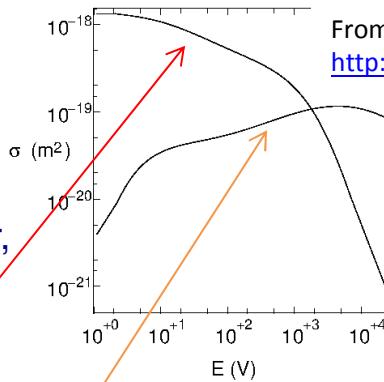
- WARP 3D is a particle-in-cell code, developed to achieve end-to-end 3D self-consistent time-dependent simulations of beam.

✓ acceleration, focusing and compression along accelerator,
 ✓ Particle loss at walls, interaction with desorbed gas and electrons, halo
 ✓ neutralization from plasma in chamber.

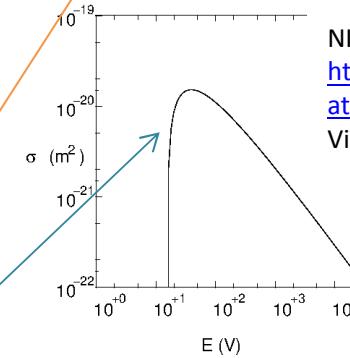
- WARP 3D being further developed to support PXIE

- Includes multiple interactions

- Charge exchange $H^- + H \rightarrow H + H^-$
- Ionization $e^- + H \rightarrow H^+ + 2 e^-$
- Detachment $H^- + H \rightarrow 2 H + e^-$
- Detachment $H^- + H_2 \rightarrow H + H_2 + e^-$
- Ionization $e^- + H_2 \rightarrow H_2^+ + 2e^-$
- Ionization $H^- + H_2 \rightarrow H^- + H_2^+ + e^-$

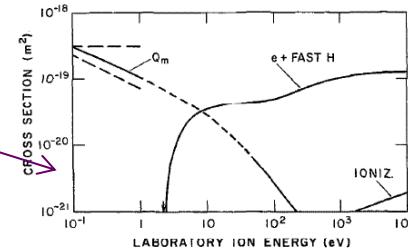


From Aladdin cross section database
<http://www-cfadc.phy.ornl.gov/home.html>

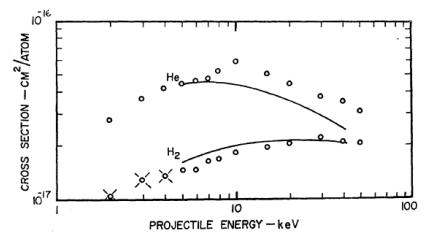


NIST Electron impact cross sections
<http://physics.nist.gov/PhysRefData/Ionization/Xsection.html>
 Via TxPhysics library

A. V. Phelps, J. Phys. Chem. Ref. Data, 19, 653(1990).

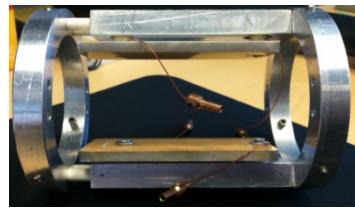


J. F. Williams, Phys. Rev., 154, 9(1967).

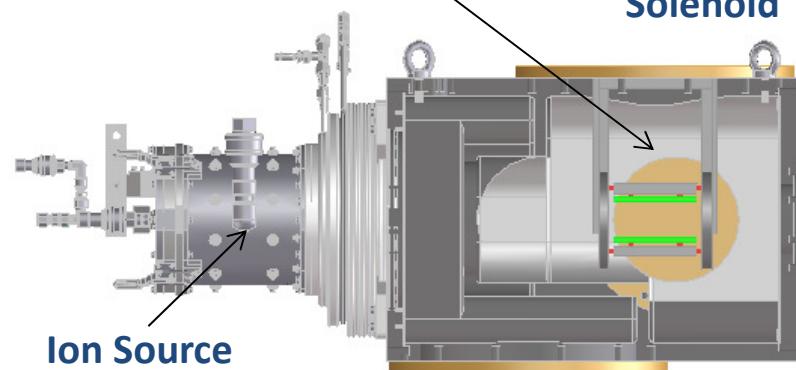
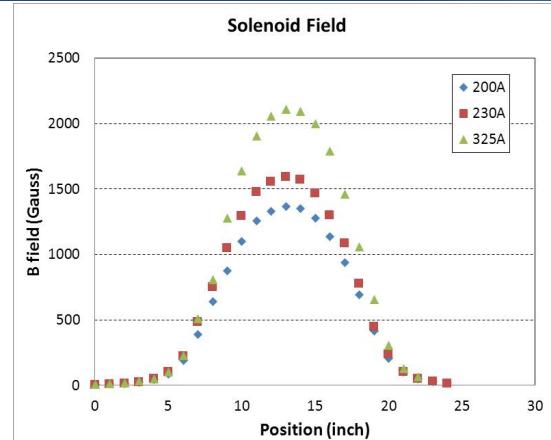


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Chopper Simulation Benchmark Experiment Setup



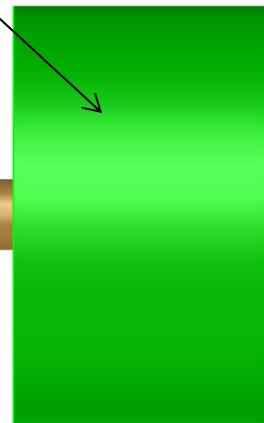
Chopper



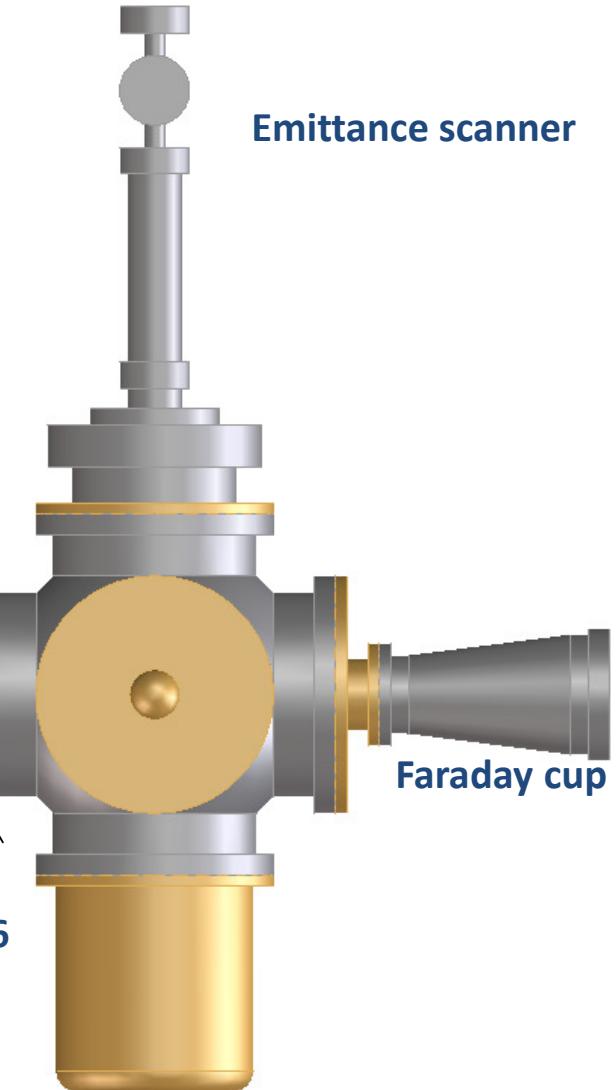
Ion Source



Solenoid



Simulation shows that @ 16 KeV, there is a beam waist between the solenoid and emittance scanner.



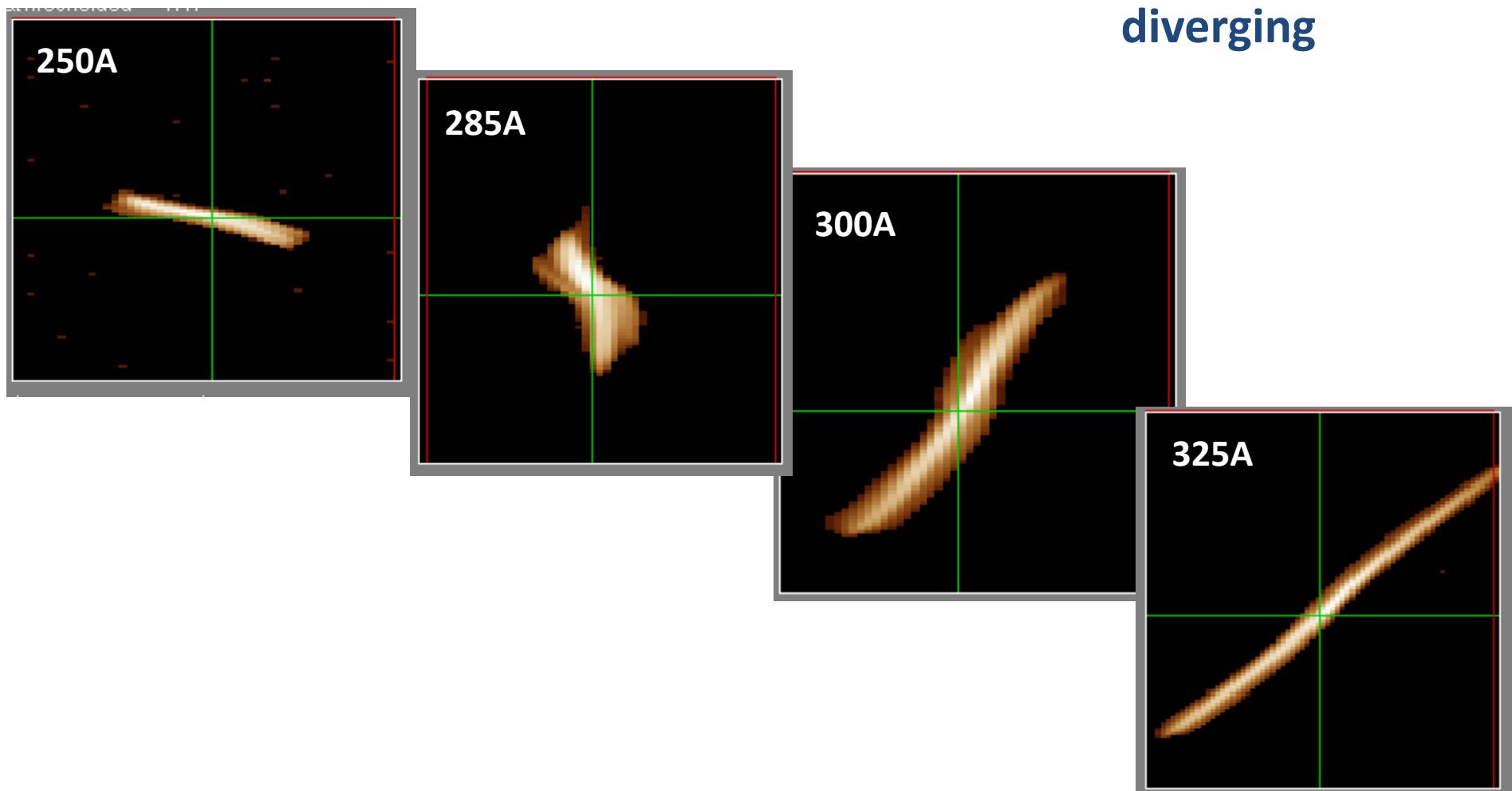
Emittance scanner

Over-focused Beam

Stronger solenoid field



Beam is more diverging

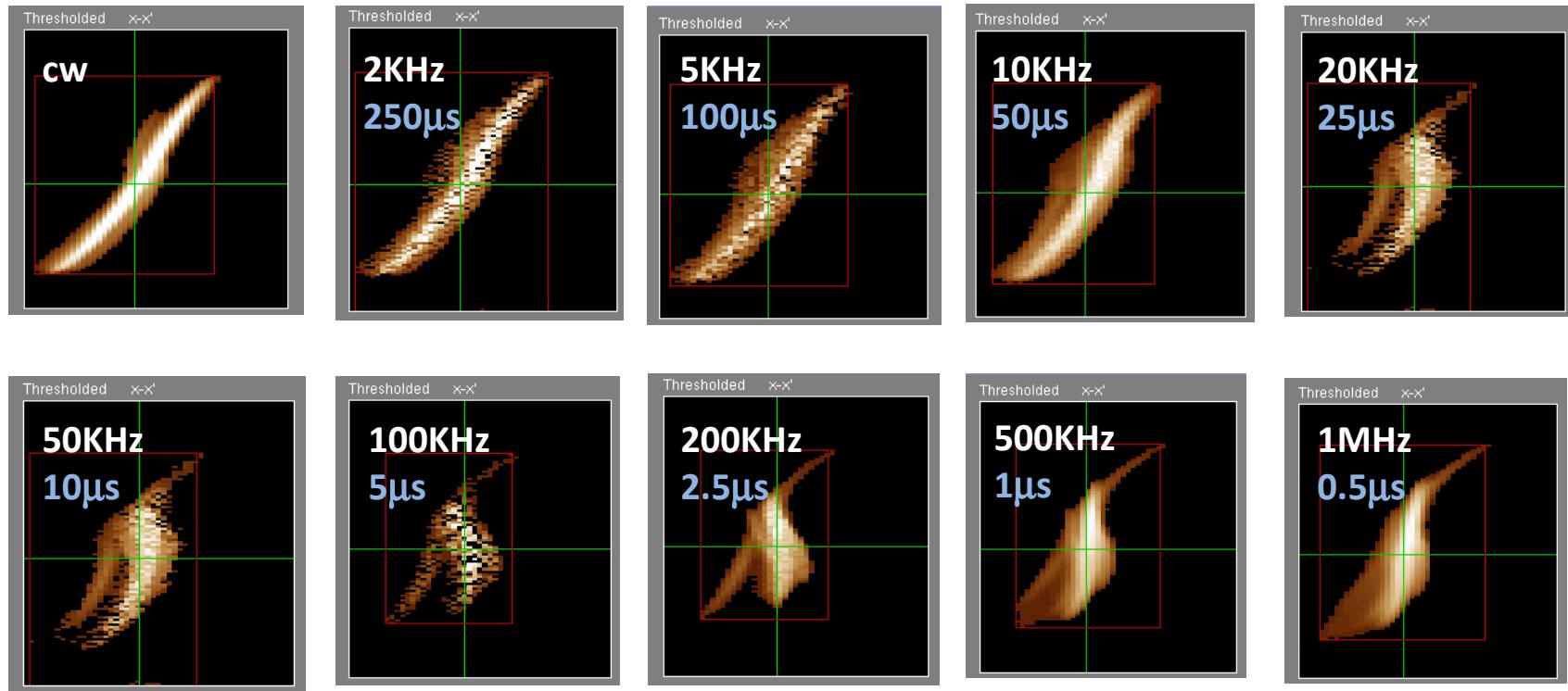


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16 KeV, 3 mA H- Beam pulsed @ 50% duty factor

Pulse width

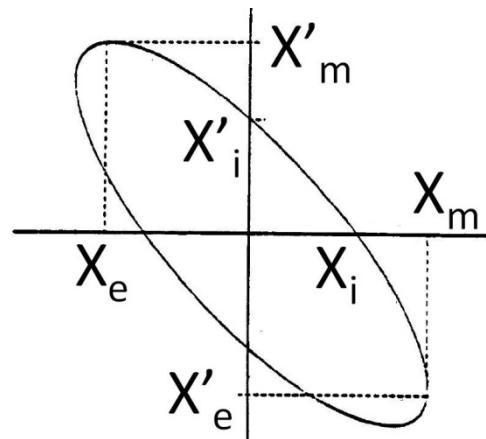
shorter



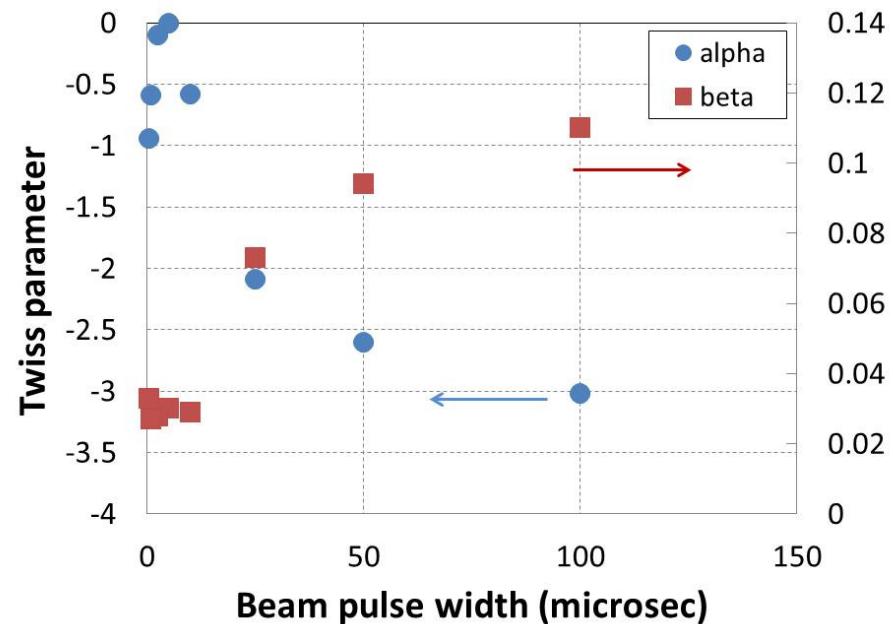
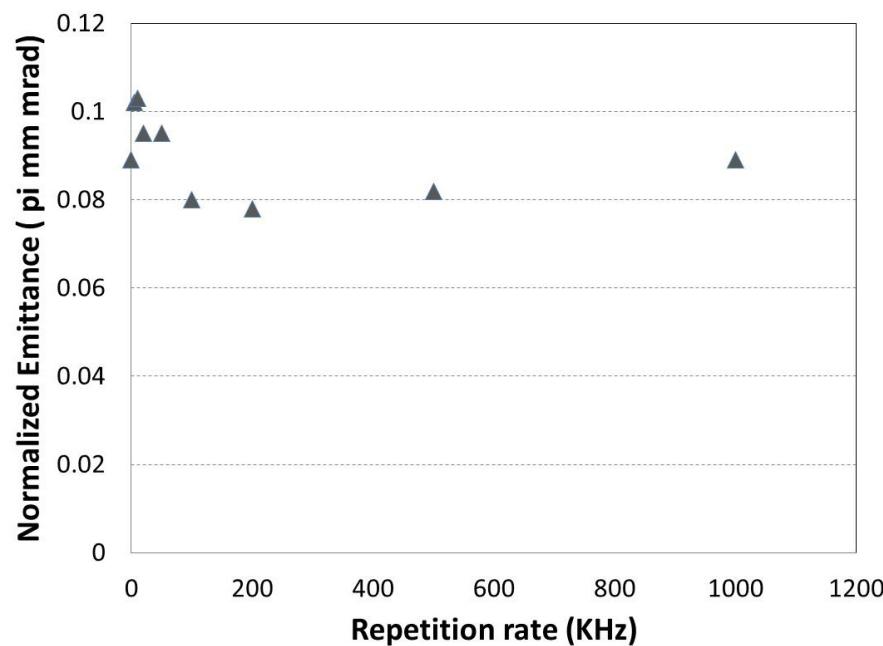
Higher repetition rate → Less space charge neutralization
Beam waist moves downstream

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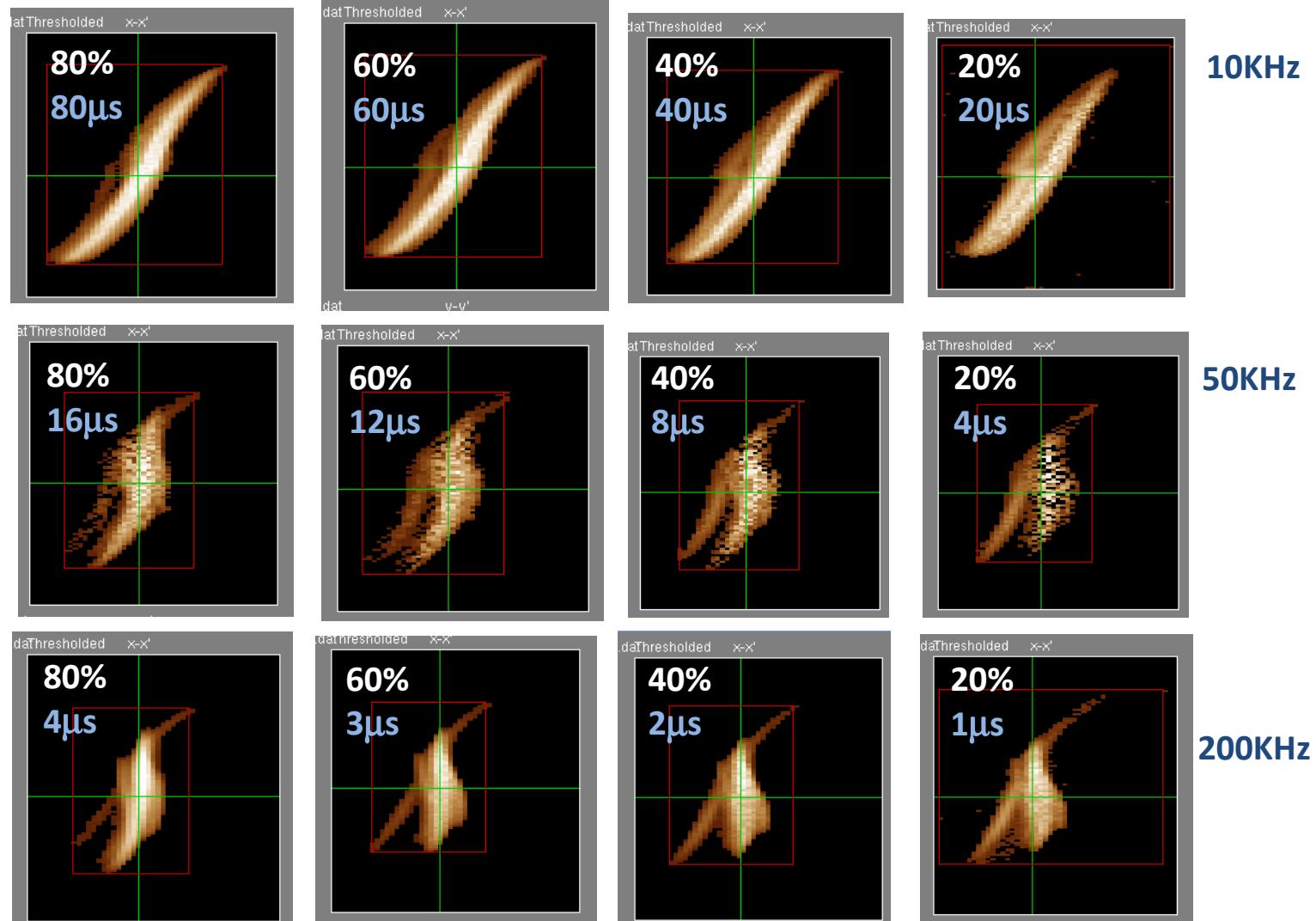
Emittance and Twiss parameters vs. Rep Rate



$$\alpha = -\frac{x_e}{x_i} = -\frac{x'_e}{x'_i}$$
$$x_m = \sqrt{\beta \epsilon}$$

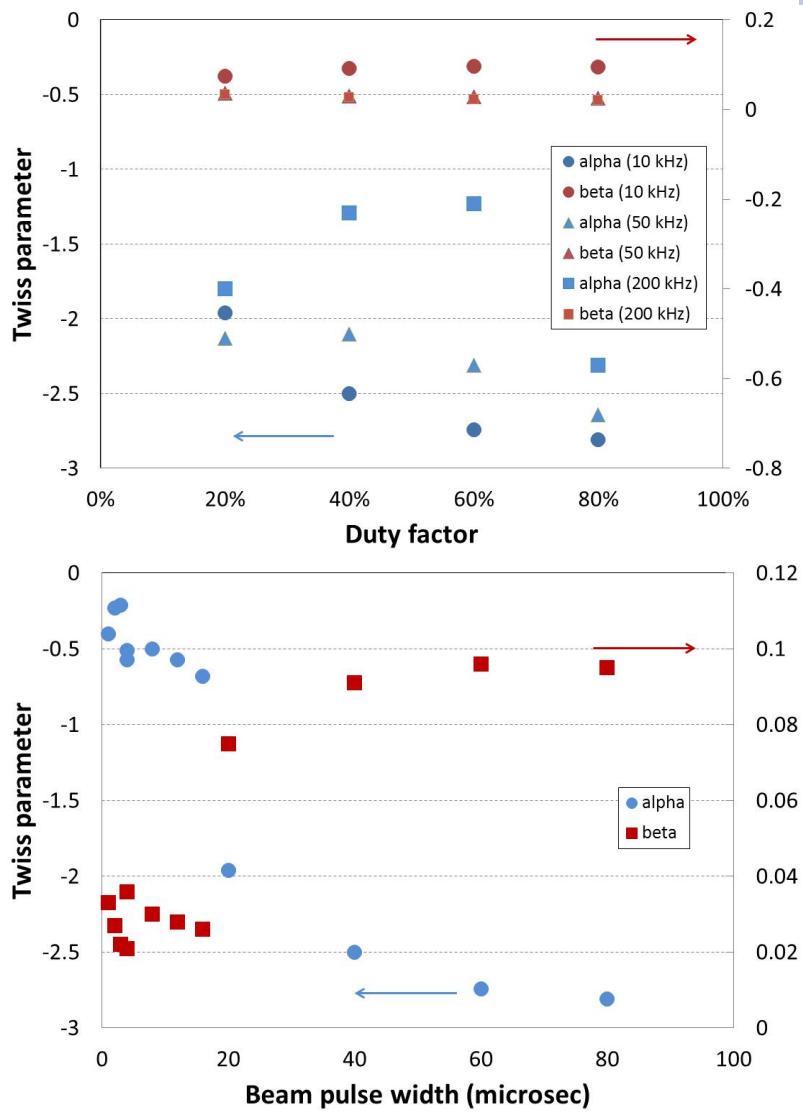
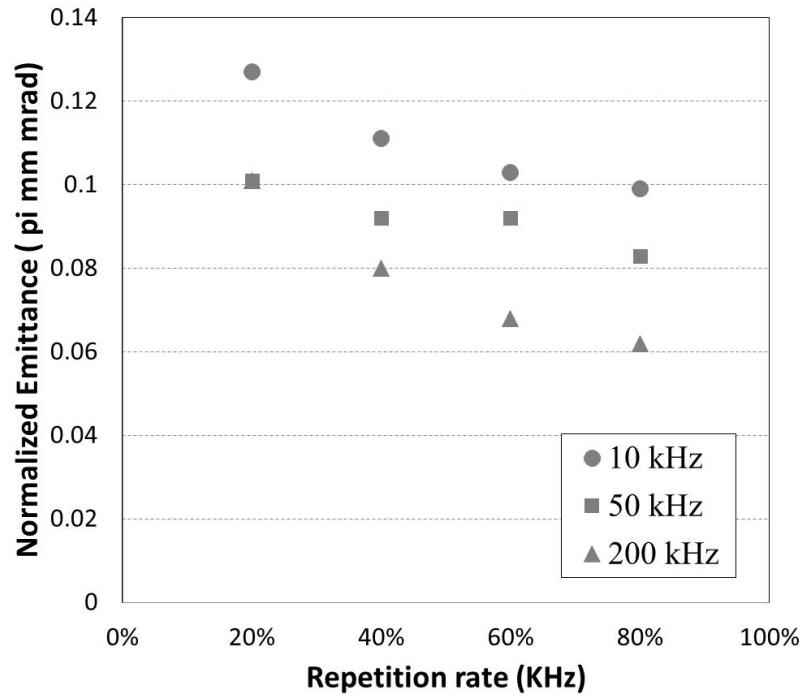


Effect of Pulse Duty factor



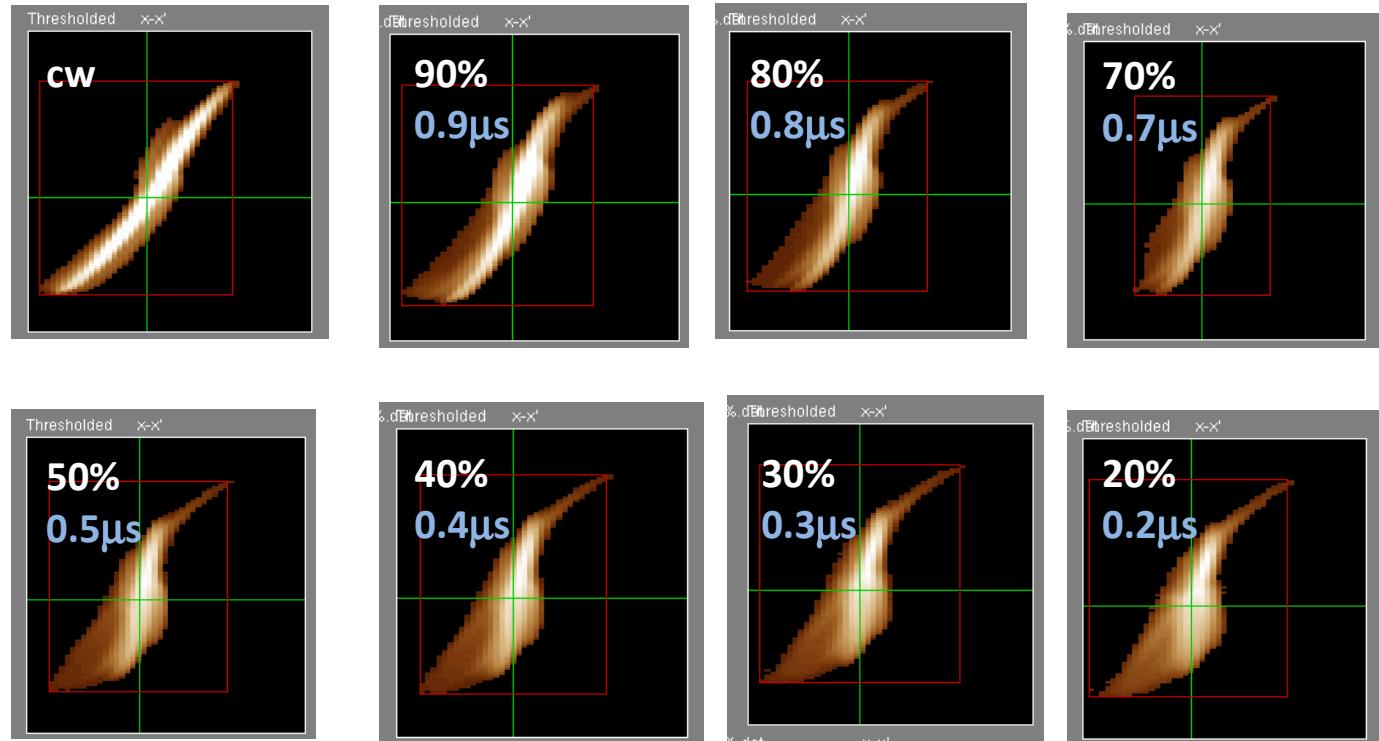
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Emittance and Twiss parameters vs. Pulse Duty Factor



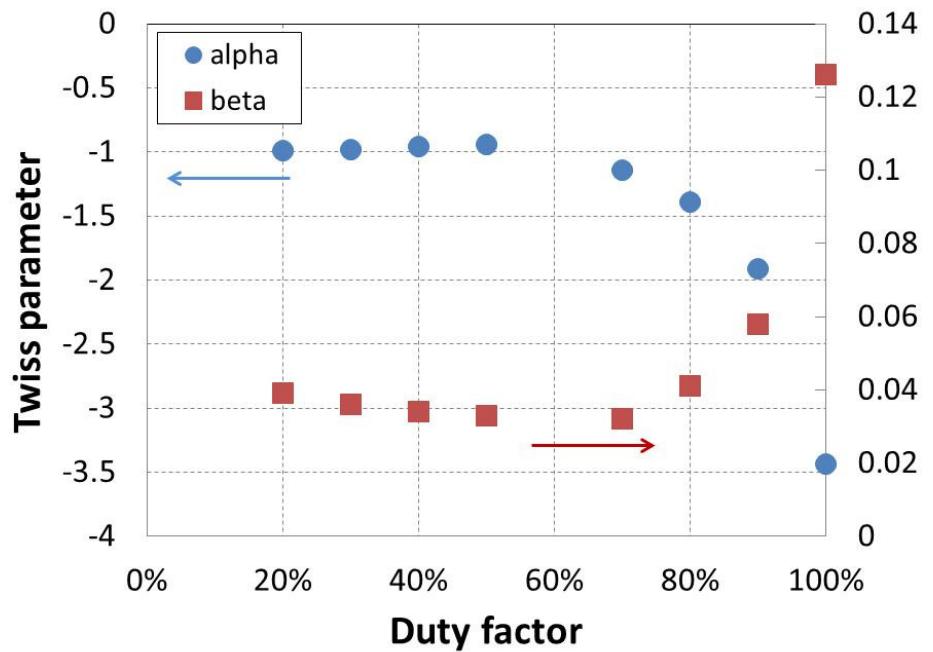
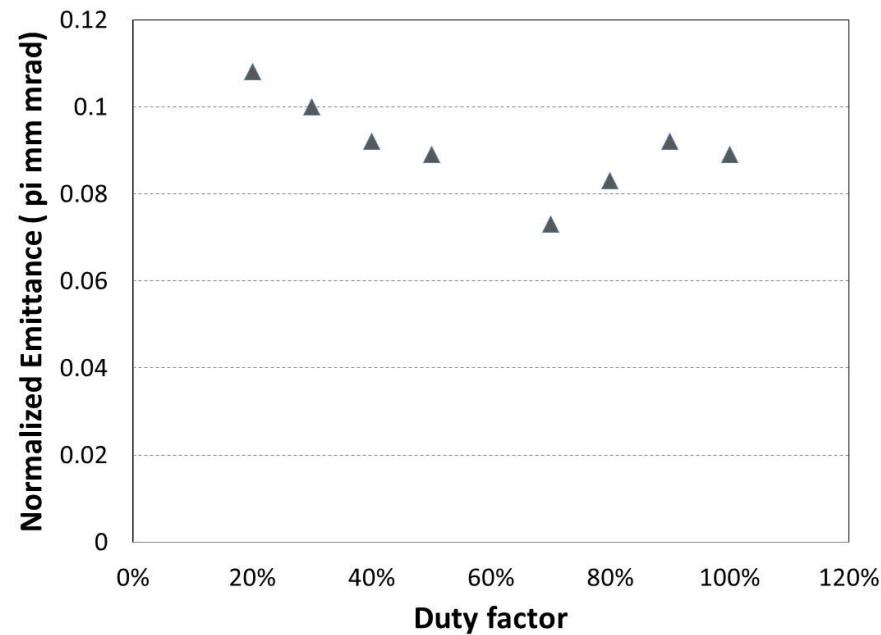
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16 KeV, 3 mA H- Beam pulsed @ 1 MHz



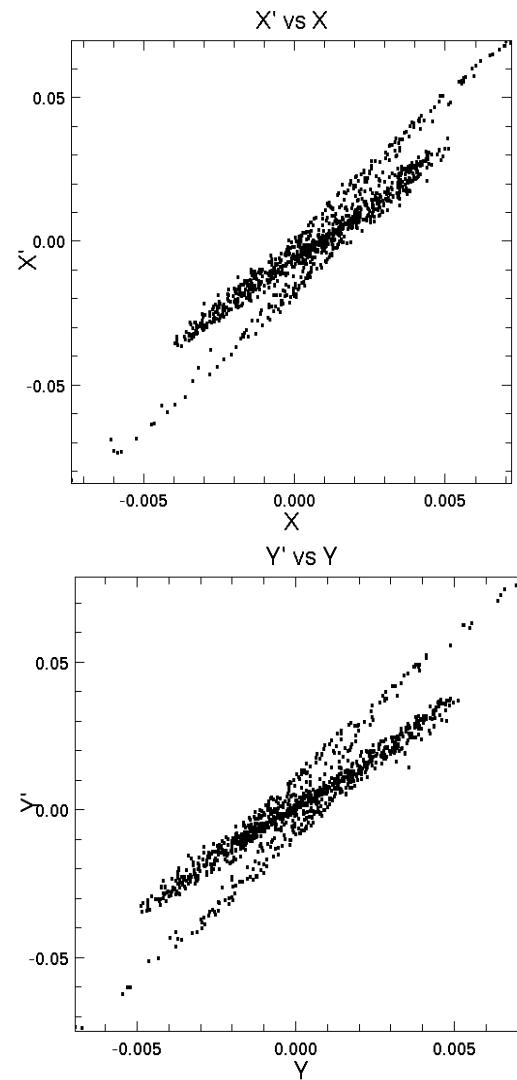
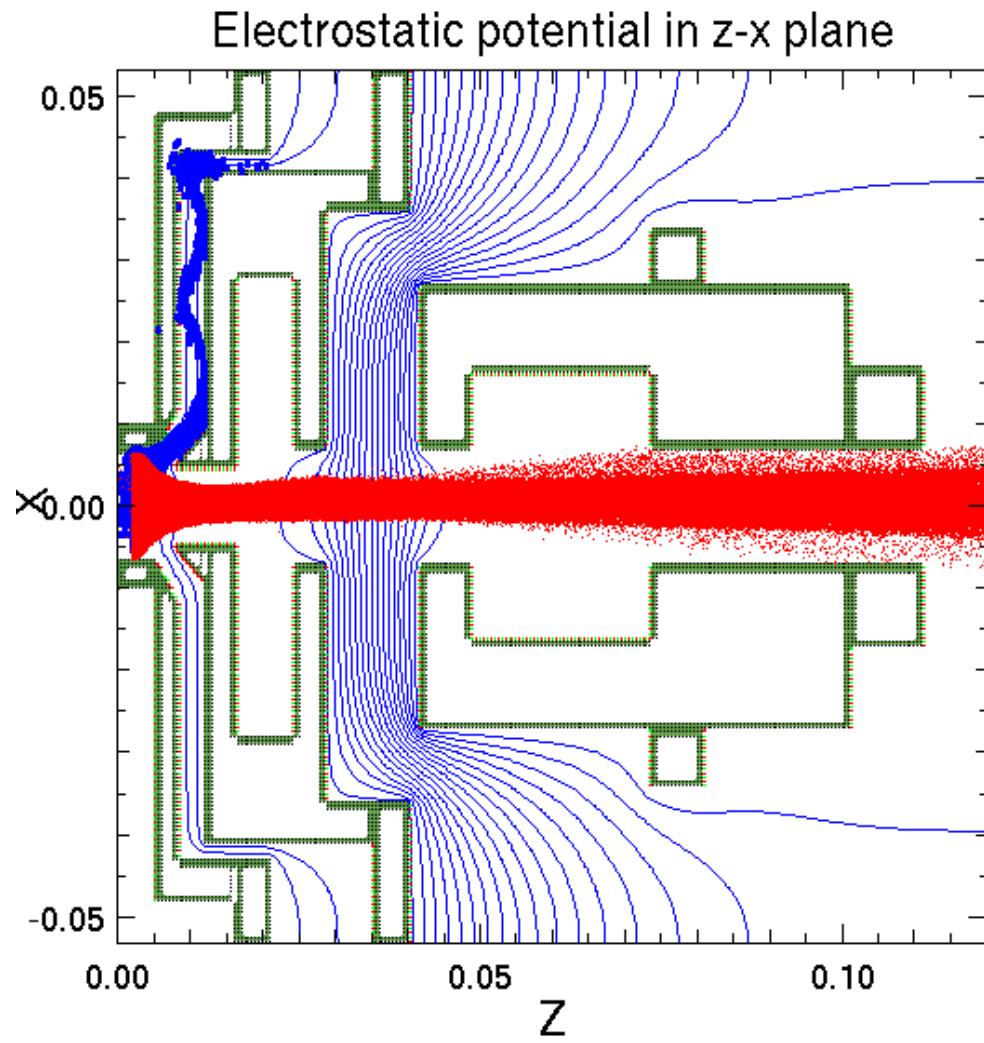
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Emittance and Twiss parameters @1MHz



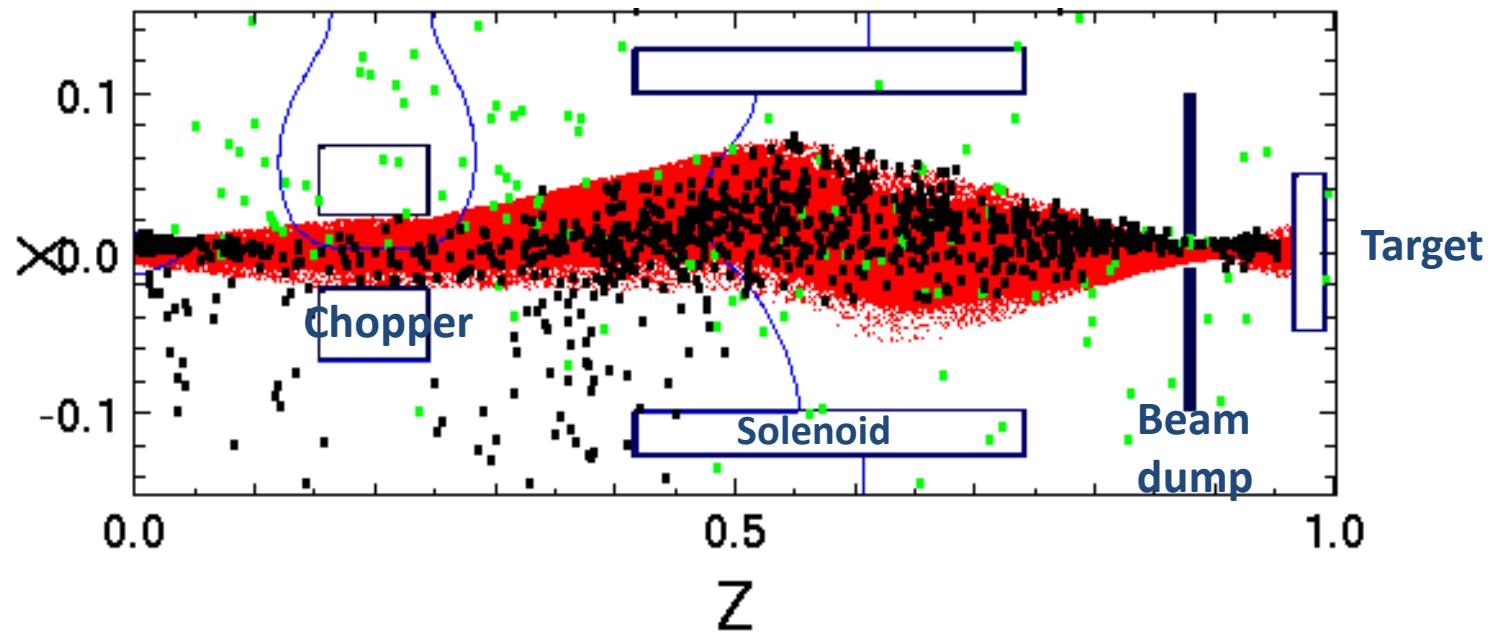
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WARP Simulation of H- Beam Extraction (@ 16kV, 3 mA)



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WARP Simulation of Chopper + Solenoid (Work in progress)

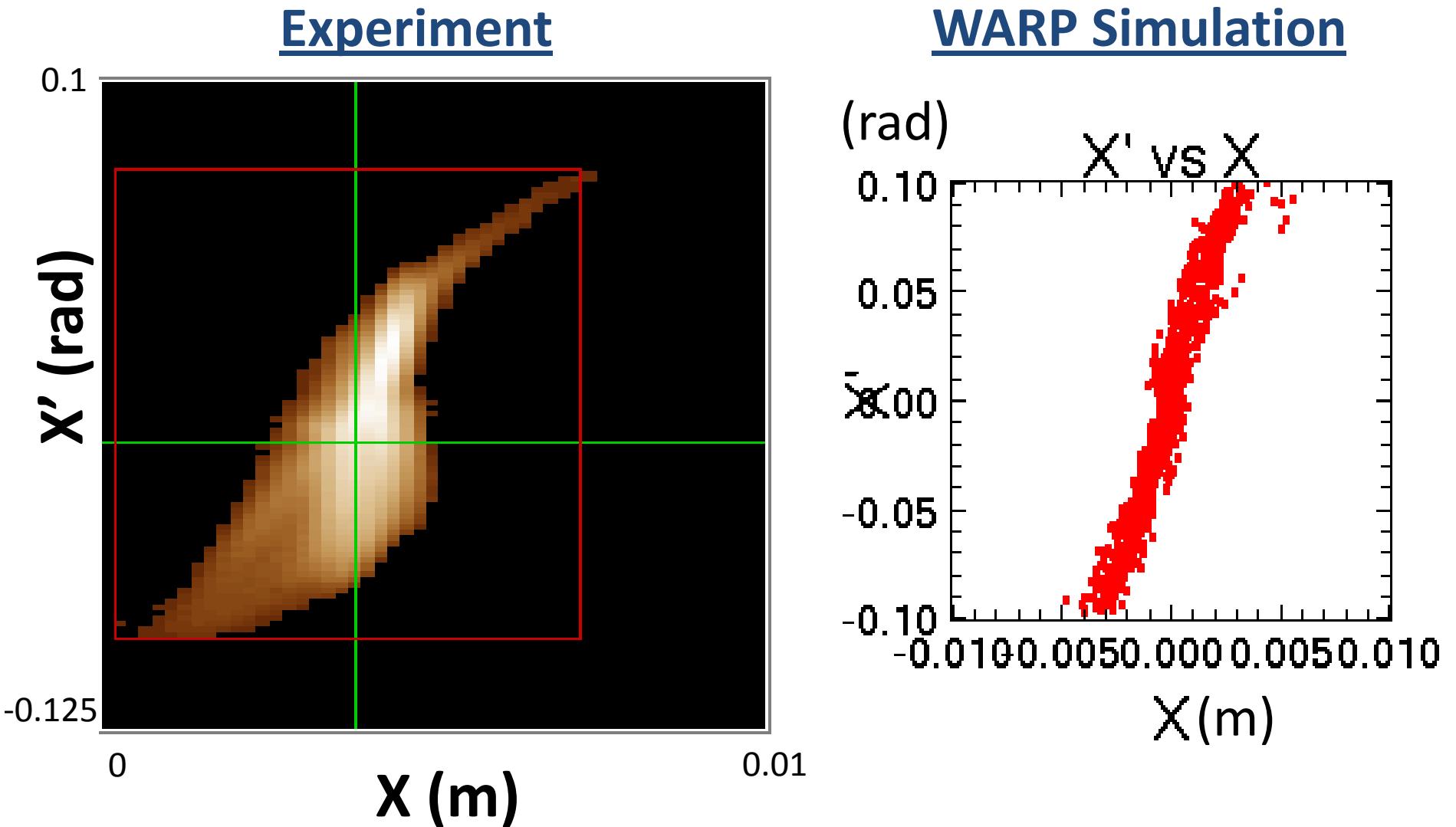


- H^-
- Electron
- H_2^+

- Use the beam ensemble simulated by WARP

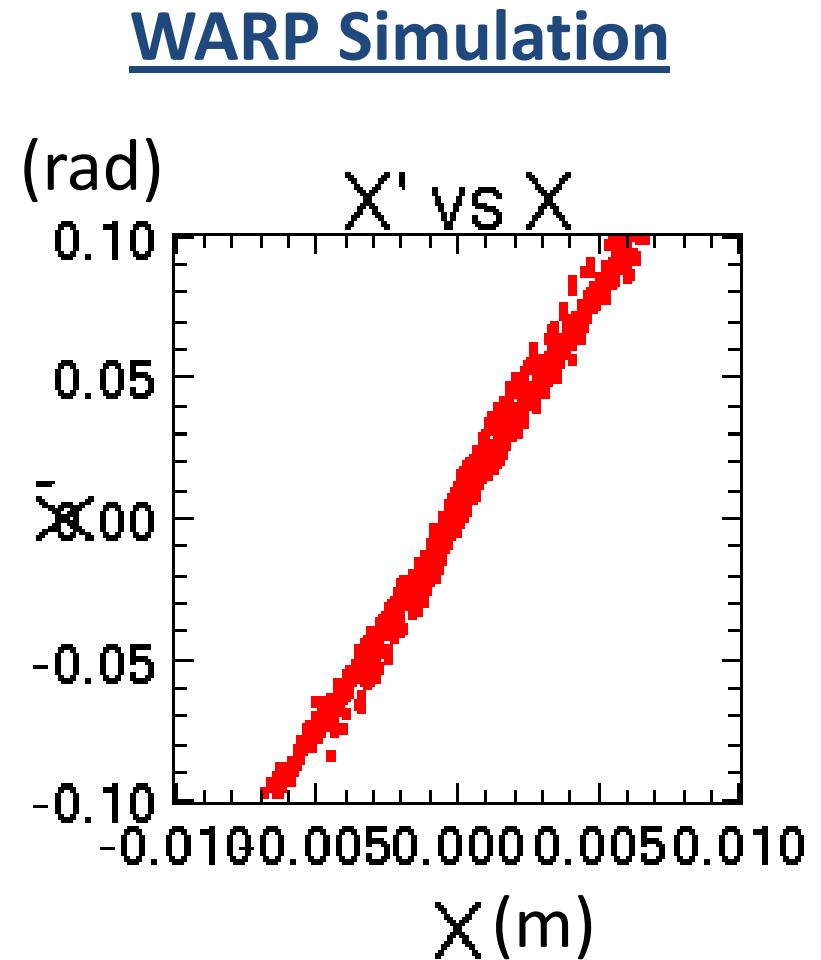
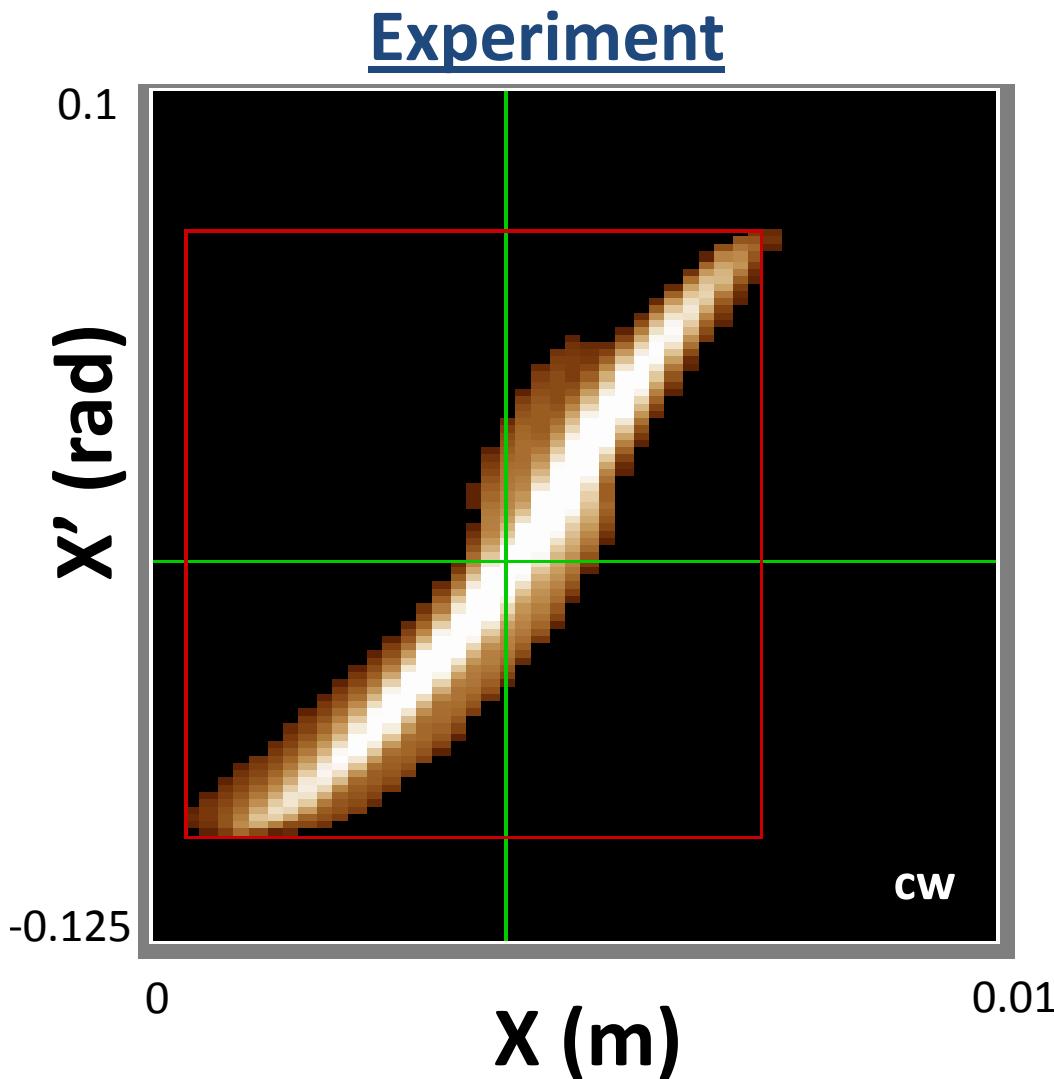
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16 KeV, 3 mA H- Beam (pulsed @ 1 MHz 20%)



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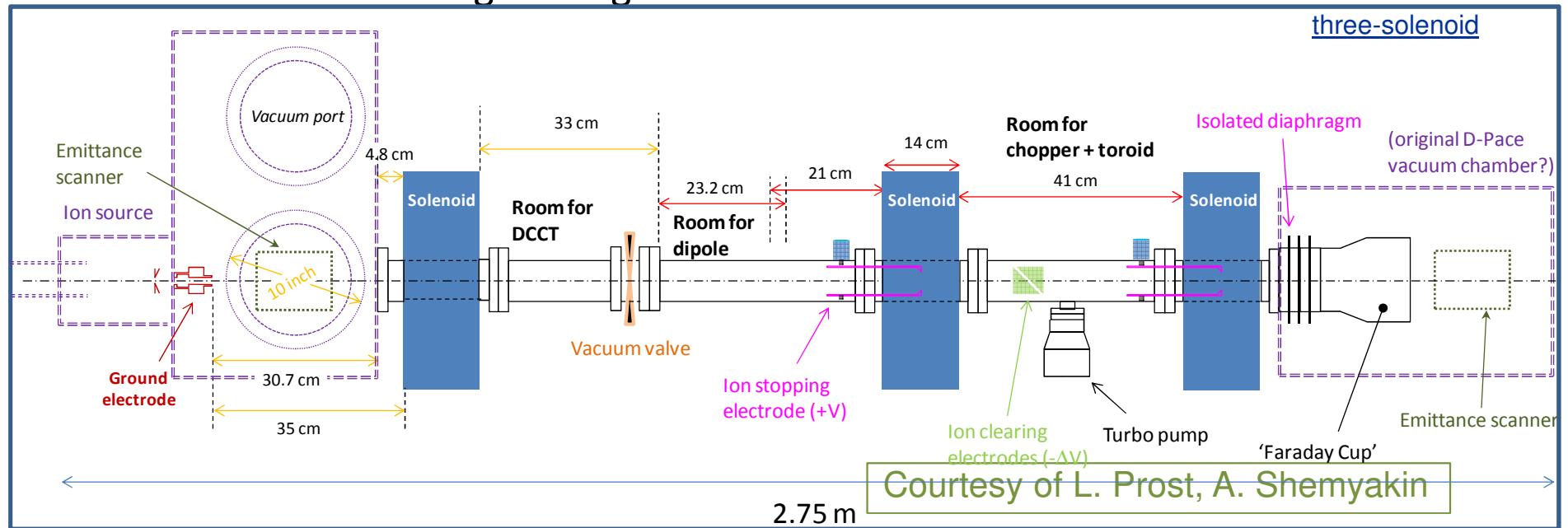
16 KeV, 3 mA H- Beam (CW)



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Future Plan

- WARP 3D simulation
 - Continue simulations of 3 mA, 16 keV H- beam dynamics in a chopper and solenoid as in the benchmark experiment
 - Emittance and twiss parameter vs. pulse repetition rate
 - Comparison between simulation and experimental results
- Time-dependent simulation of three-solenoid LEBTs including particle interactions with background gas.



Summary

- Time-dependent WARP 3D simulations of particle interactions, such as electron detachment, charge exchange, H- ionizations etc. in the LEBT are still ongoing.
- Both experimental and preliminary simulation results showed that, from the chopper to the entrance of RFQ, emittance increases.
- Chopper simulation benchmark experiment has been performed at various pulse duty factor and repetition rate.
- WARP 3D simulations in progress for benchmarking.